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Seismicity of the Earth 1900–2013

East African Rift

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SUMMARY

The East African Rift system (EARS) is a 3,000-km-long Cenozoic age continental rift extending from the Afar triple junction, between the horn of Africa and the Middle East, to western Mozambique. Sectors of active extension occur from the Indian Ocean, west to Botswana and the Democratic Republic of the Congo (DRC). It is the only rift system in the world that is active on a continent-wide scale, providing geologists with a view of how continental rifts develop over time into oceanic spreading centers like the Mid-Atlantic Ridge.

Rifting in East Africa is not all coeval; volcanism and faulting have been ongoing phenomena on the continent since the Eocene (~45 Ma). The rifting began in northern East Africa, and led to the separation of the Nubia (Africa) and Arabia plates in the Red Sea and Gulf of Aden, and in the Lake Turkana area at the Kenya-Ethiopia border. A Paleogene mantle superplume beneath East Africa caused extension within the Nubia plate, as well as a first-order topographic high known as the African superswell which now includes most of the eastern and southern sectors of the Nubia plate. Widespread volcanism erupted onto much of the rising plateau in Ethiopia during the Eocene-Oligocene (45–29 Ma), with chains of volcanoes forming along the rift separating Africa and Arabia. Since the initiation of rifting in northeastern Africa, the system has propagated over 3,000 km to the south and southwest, and it experiences seismicity as a direct result of the extension and active magmatism.

Today extension and magmatism are localizing in distinct eastern, western, and southwestern branches marking the edges of two or more microplates between the sub-parallel zones of extension in East Africa. The borders of the microplates (known as Victoria and Rovuma) with the Nubia plate to the west and Somalia plate to the east now represent the most seismically active zones on the continent where normal faulting earthquakes occur on a monthly basis. They are also the sites of volcano-tectonic earthquakes. Along the rift, models of sparse Global Positioning System (GPS) data and earthquake-slip vectors predict average spreading rates of 1–4 mm/yr, increasing from north to south in the western branch, and increasing from south to north in the east.

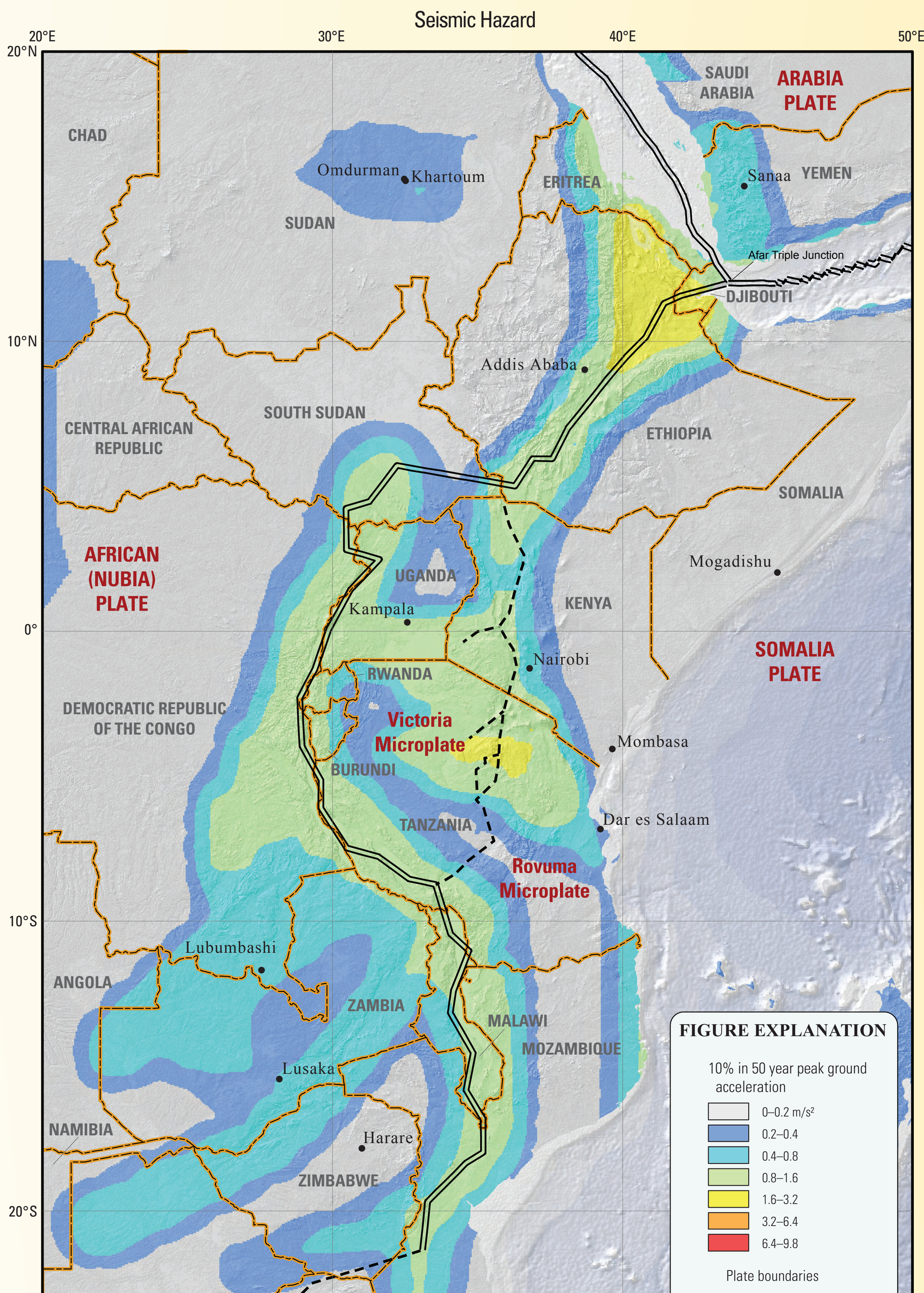
Seismicity in the East African Rift is widespread, but displays a distinct pattern. Seismicity is characterized by mainly shallow (<40 km) normal faults (earthquakes rupturing as a direct result of extension of the crust), and volcano-tectonic earthquakes. The majority of events occur in the 10–25-km depth range. This pattern is widespread throughout the EARS, and provides insight into the relationship between depth of earthquakes, the deformation of continental lithosphere, and magmatic processes in many sectors of the rift.

The three limbs of the Afar triple junction zone experience major earthquakes, as well as frequent volcanic eruptions and dike intrusions. The magnitude of earthquakes during volcano-tectonic events is usually less than magnitude 6 (M6), but large volumes of magma accommodating plate opening may occur during these intense, smaller magnitude swarms. The largest earthquakes recorded in this area occurred in a swarm, along a section of the evolving Arabia-Nubia plate boundary in Afar in August 1989. Studies of this earthquake swarm show that the events occurred as a result of slip on conjugate normal faults bounding the narrow Dobi graben. The swarm, made up of 25 M≥4.2 earthquakes, occurred over 48 hours from 11:17 UT August 20, 1989. The events were all shallower than 15 km as a result of the thin crust beneath the triple junction compared to the surrounding continental crust. Conversely, the deepest earthquake ever recorded on the African continent (~62 km) also occurred beneath the Afar triple junction on November 8, 1978. This M4.9 earthquake occurred beneath an active spreading segment, and was probably associated with the movement of magma at depth during the rifting episode.

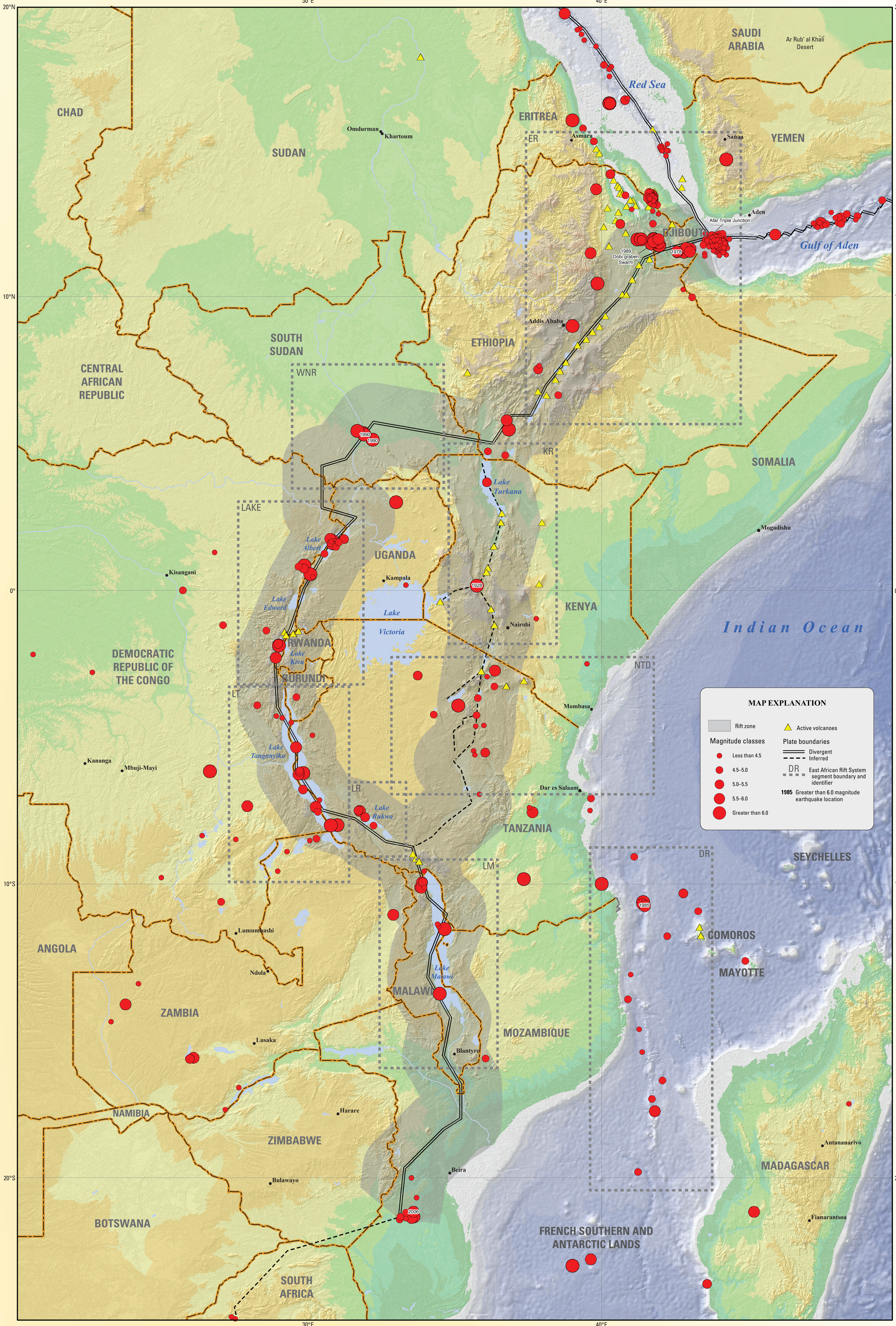
The western branch is divided into three main segments: The northern and middle segments border the Nubia-Victoria microplate boundary, and the southern segment borders the Nubia-Rovuma boundary. The northern segment comprises the West Nile region (WNR), and Lakes Albert, Kivu, and Edward (LAKE); the middle segment includes Lakes Tanganyika and Rukwa (LT, LR); and the southern segment encompasses Lake Malawi and central Mozambique (LM). The two largest instrumentally recorded events in Africa occurred about 300 km north of Lake Albert in the WNR, in an area of Mesozoic (250–65 Ma) rifting. These M7.1 earthquakes struck four days apart in May 1990, both at ~15 km depth. Their tectonic relationship to the Albert rift system or Mesozoic faults remains unclear. The most recent major earthquake to strike the region occurred on February 22, 2006. This M7.0 event struck at a depth of 11 km in west-central Mozambique around midnight local time, killing two and injuring 15. The earthquake was felt in Mozambique, Zimbabwe, Swaziland, South Africa, and Zambia, but no major structural damage was reported.

The eastern branch is a discontinuous system of rifts, most of which have experienced magmatism since their onset. From north to south, these are the Ethiopian Rift (ER), the Kenya Rift (KR), the northern Tanzania divergence (NTD), and the Davie Ridge (DR). The Kenya Rift experienced a major M6.9 earthquake in 1928, but has hosted only small magnitude swarms since then. As in the Afar and Ethiopian rift sectors where magma supply appears to be abundant, dike intrusions in the Kenya Rift accommodate extensional strain at lower stress levels than are required to cause slip along large fault systems bounding the rift. This generally results in relatively smaller earthquakes. Seismicity near the northern Tanzania Divergence marks the diffuse, volcanically active Victoria-Somalia plate boundary. Consistent with the widespread magmatism in this rift sector, earthquake magnitudes are generally less than M6, and are the result of normal faulting. The Davie Ridge marks the Rovuma-Somalia plate boundary in the oceanic lithosphere of the western Indian Ocean basin. On May 14, 1985, two M6.0–6.3 earthquakes struck this area, less than 100 km off the coast of northern Mozambique.

Seismic Hazard



For region to the north see: USGS Open File Report 2010–1083-K Middle East and vicinity http://pubs.usgs.gov/of/2010/1083/k



WGS 1984 Projection

SCALE 1:8 500 000

Cartography: Eric S. Jones
Cartography Database: Eric S. Jones, Gregory M. Smoczyk

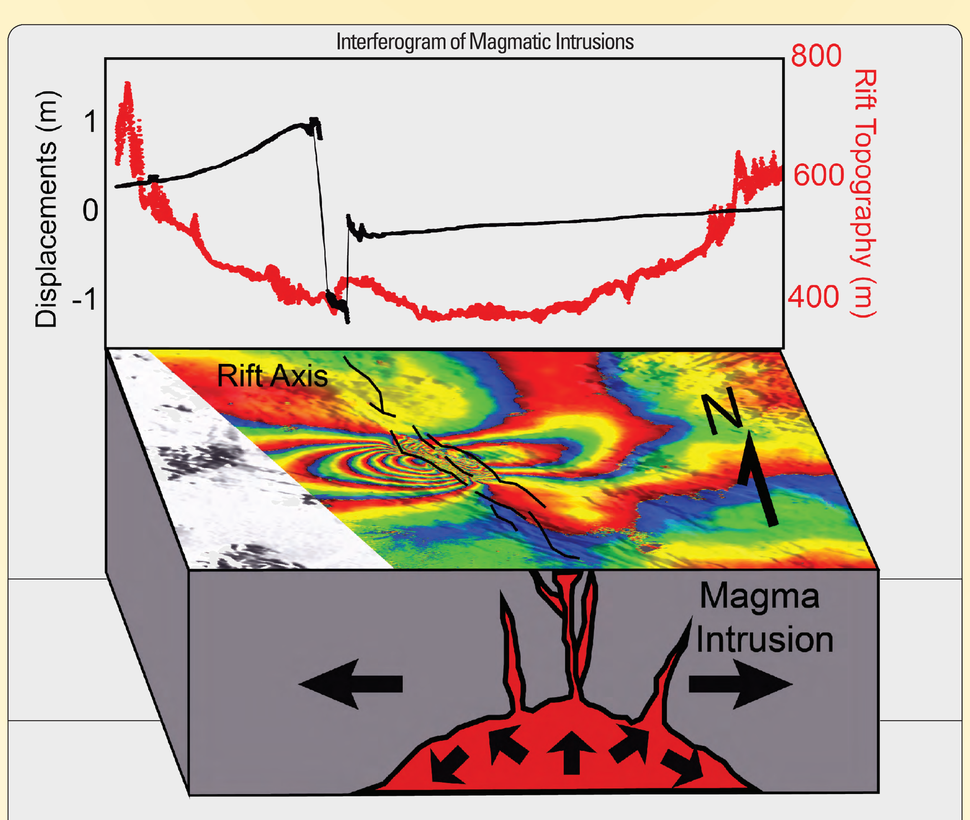
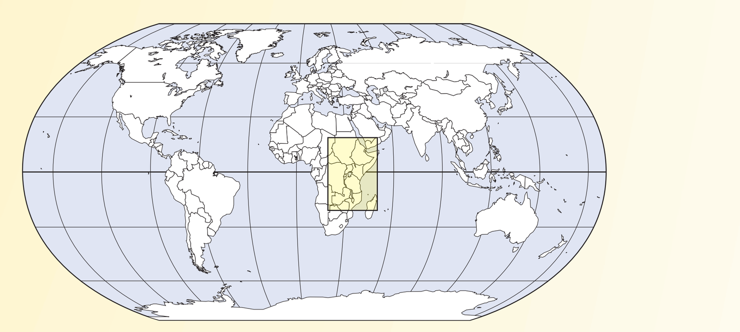


Figure 1. Most of the tectonic processes active in the East African Rift System are related to rifting and associated magmatic intrusions. These processes are generally accompanied by significant crustal deformation, which can be imaged directly through the use of Interferometric Synthetic Aperture Radar (InSAR). InSAR is a remote sensing technique that uses two or more synthetic aperture radar images collected before and after a deformational event to generate maps of the surface displacements associated with that process, by exploiting differences in the phase of the waves returning to the satellite. This figure shows an example of the phase changes and associated deformation caused by a dike intrusion in October 2008, in Ethiopia generated from data collected by the Advanced Land Observing Satellite (ALOS) on September 19, 2008, and December 15, 2008. The 'fringes' in the resulting interferogram (each color cycle from blue to blue) represent approximately 12 cm of deformation in the radar's line of sight. This interferogram shows displacements caused by surface spreading and subsidence due to the shallow injection of magma, and the formation of dikes rising from a deeper magma source. The complex signal near the center of the fringes also indicates surface cracking and faulting that occurs as the injected magma approaches and breaches the Earth's surface. We have overlaid the interferogram on a three-dimensional schematic (and generic) interpretation of the magmatic intrusion event that caused this pattern of surface deformation.



MAP LOCATION

RIFT ZONES

In the East Africa Rift System, rifting and deformation is understood to be more broadly distributed than along a single linear feature; as such, we represent the approximate width of the deformation zones here with gray zones. The shaded regions here are meant to be representative of distributed deformation, rather than precisely defining the extent of that deformation. In this interpretation, plate boundaries represent the rift axis.

DATA SOURCES

The earthquake locations shown on the main map (left) and on the depth profiles are taken from the global 1900–2007 Centennial catalog (Engdahl and Villaseñor, 2002), a catalog of high-quality depth determinations for the period 1964–2002 (Engdahl, personal comm., 2003), and USGS-NEIC for the period 2003-2013. Major earthquakes (M>=6.0) are labelled with the year of occurrence (Tarr, and others, 2010).

The seismic Hazard and Relative Plate Motion panel displays the generalized seismic hazard of the region (Giardini, and others, 1999) and representative relative plate motion vectors using the MORVEL model (DeMets, and others, 2010.).

Base map data sources include GEBCO (2008), Esri's Ocean Basemap, Volcanoes of the World dataset (Siebert and Simkin, 2002), plate boundaries (Bird, 2003), and Digital Chart of the World (1992).

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